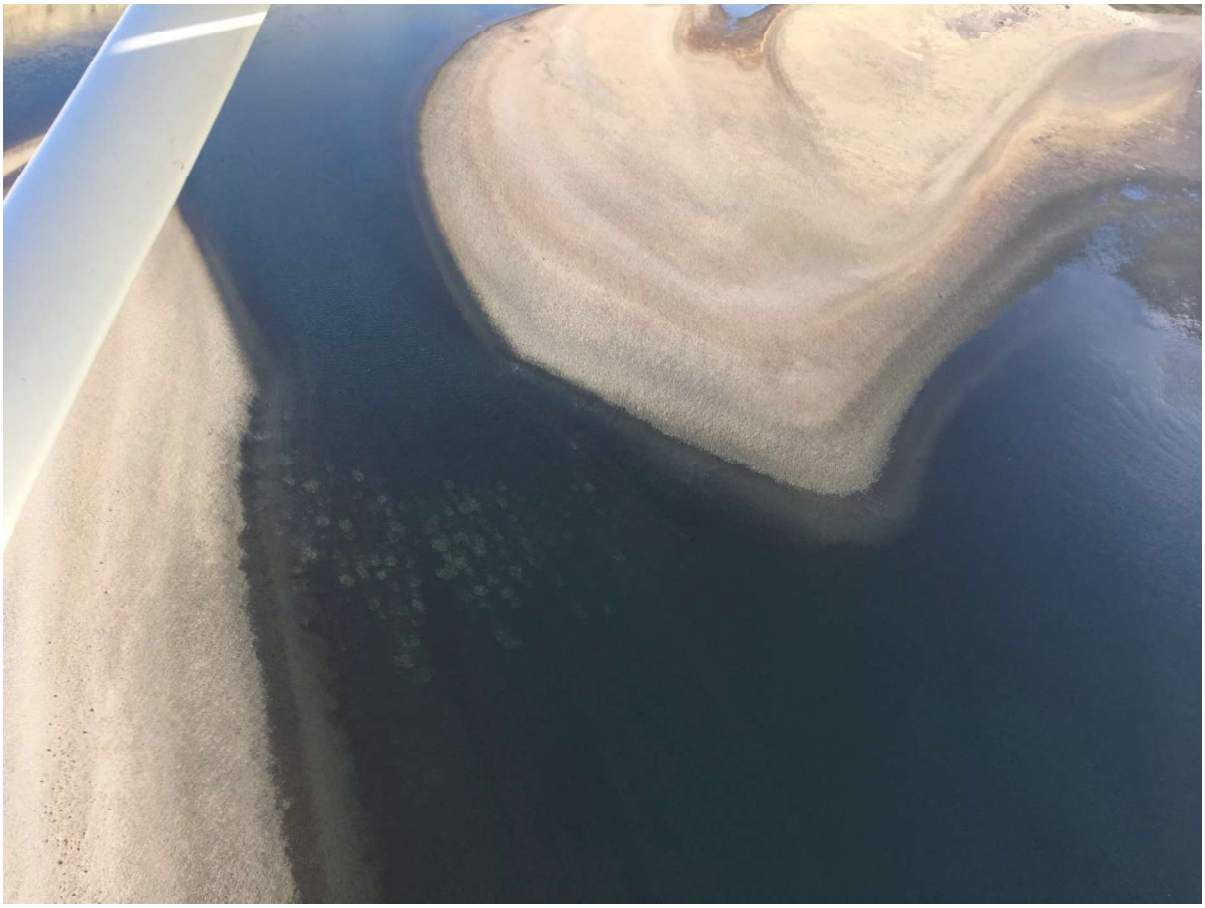
Hanford Reach Fall Chinook Salmon Redd Monitoring Report for Calendar Year 2019



Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

Contractor for the U.S. Department of Energy
under Contract DE-AC06-09RL14728

P.O. Box 650
Richland, Washington 99352

Hanford Reach Fall Chinook Salmon Redd Monitoring Report for Calendar Year 2019

J. J. Nugent
Mission Support Alliance

Date Published
October 2020

Prepared for the U.S. Department of Energy

Assistant Secretary for Environmental Management
Contractor for the U.S. Department of Energy

under Contract DE-AC06-09RL14728

P.O. Box 550
Richland, Washington 99352

APPROVED
By Sarah Harrison at 1:34 pm, Nov 05, 2020

Release Approval Date

Approved for Public Release
Further Dissemination Unlimited

CONTENTS

FIGURES

TABLES

1.0 INTRODUCTION

The U.S. Department of Energy, Richland Operations Office (DOE-RL) conducts ecological monitoring on the Hanford Site to collect and track data needed to ensure compliance with an array of environmental laws, regulations, and policies governing DOE-RL activities. Ecological monitoring data provide baseline information about the plants, animals, and habitats under DOE-RL stewardship at the Hanford Site required for decision making under the *National Environmental Policy Act* (NEPA) and *Comprehensive Environmental Response, Compensation, and Liability Act*. DOE/EIS-0222, *Final Hanford Comprehensive Land Use Plan Environmental Impact Statement* (CLUP) evaluates the potential environmental impacts associated with implementing a comprehensive land-use plan for the Hanford Site for at least the next 50 years, and ensures that DOE-RL, its contractors, and other entities conduct activities on the Hanford Site in compliance with NEPA.

The vision for the DOE-RL-managed portion of the Hanford Site focuses not only on the cleanup of nuclear facilities and waste sites but on the protection of groundwater and the Columbia River, as well as and the restoration of the Hanford Site lands for access and use (DOE/RL-2009-10). To reach these goals DOE-RL is working closely with partners, such as the U.S. Fish and Wildlife Service and National Park Service, to enable use of the Hanford Site land consistent with the CLUP. As the Hanford Site moves toward accomplishing this vision, monitoring the ecological resources present to determine whether there is a need for conservation and/or protection of any resources will be critical for making informed decisions for responsible site stewardship.

DOE-RL places priority on monitoring plant and animal species or habitats that fit into one or more of the categories below:

- Regulatory protections or requirements
- Rare and/or declining species (i.e., federally or state listed endangered, threatened, or sensitive)
- Significant interest to federal, state, or Tribal governments or the public.

DOE/RL-96-32, *Hanford Site Biological Resources Management Plan*, (BRMP) ranks wildlife species and habitats (Levels 0–5) based on the level of concern for each resource. Fall Chinook salmon (*Oncorhynchus tshawytscha*) spawning areas are ranked as Level 5 resources, the highest ranking level in BRMP. According to the BRMP, "resources classified as Level 5 are the rarest and most sensitive habitats and species and are considered irreplaceable or at risk of extirpation or extinction." The management goal of Level 5 resources is preservation and requires a high level of status monitoring.

Commonly referred to as king salmon, Chinook are the largest of the Pacific salmon (Myers et al. 1998, Netboy 1958). The Columbia River supports three major runs (spring, summer, and fall) of Chinook salmon, generally based on the season during which the adults re-enter the estuary to begin their upstream migration to spawn. Chinook salmon that spawn in the Hanford Reach of the Columbia River are fall-run fish. Fall Chinook salmon enter freshwater at an advanced stage of maturity, move rapidly to their spawning areas on the mainstem or lower tributaries of the rivers, and spawn within a few days or weeks of freshwater entry (Myers et al. 1998, Fulton 1968, Healey 1991). Adult fall Chinook salmon destined for the Hanford Reach are upriver brights (fish retain their silver color during upstream migration) that enter the Columbia River in late summer and spawn in the fall. Spawning in the Hanford Reach typically begins in mid-October and lasts through November. The population of fall Chinook salmon that spawns in the Hanford Reach of the Columbia River is the largest run remaining in the Pacific Northwest and has regional, ecological, cultural, and economic importance that reaches areas downstream on the Columbia River and along the Pacific Ocean coast as far as southeast Alaska (Dauble and Watson 1997). These fall Chinook salmon have

been vital in efforts to preserve and restore other depleted Chinook salmon stocks in the Columbia Basin (Anglin et al. 2006).

Dauble and Watson (1997) found the initiation of spawning ranged from September 28 to October 26 with a median date of October 16. Females fan out nests or "redds" in suitable gravel substrate and deposit eggs in a pocket while males simultaneously extrude milt to fertilize the eggs. Redds are readily identifiable at this time and appear as clean swept gravel patches amidst darker undisturbed substrate covered by algae (periphyton). "Redd life" is a term describing the period during which periphyton growth has not rendered the redd substrate indiscernible from the surroundings. Redd life is typically about 6 weeks on the Hanford Reach (PNL-7289); however, redds have been recorded to remain visible for over 16 weeks (HNF-53665, HNF-56705).

Fall Chinook salmon redds have been monitored at the Hanford Site annually since 1948, including aerial counts, to provide an index of relative abundance among spawning areas and years (HNF-52190, HNF-54808, HNF-56707, HNF-58823, HNF-59813, HNF-63012, HNF-64540, HNF-64542). The counts are used to document the onset of spawning, locate spawning areas, and determine intervals of peak spawning activity. These data also allow for planning to avoid impacts such as disturbance or siltation to redds from Hanford Site activities. Understanding the location and abundance of spawning is a critical part of the management of this important population and facilitates protection of essential fish habitats safeguarded under the *Magnuson-Stevens Fishery Conservation and Management Act*.

The information collected during the aerial surveys is vitally important for the implementation of the Hanford Reach Fall Chinook Protection Program (HRFCPP; USACE 2006). The HRFCPP is an agreement among Public Utility District No. 2 of Grant County, Washington (Grant); Public Utility District No. 1 of Chelan County, Washington (Chelan); Public Utility District No. 1 of Douglas County, Washington (Douglas); DOE acting by and through the Bonneville Power Administration (BPA); National Oceanic and Atmospheric Administration Fisheries (NOAAF); Washington Department of Fish and Wildlife (WDFW); and the Confederated Tribes of the Colville Indian Reservation (CCT). The goal of this program is to protect Hanford Reach fall Chinook salmon during critical periods of their life cycle through operational constraints imposed on the Priest Rapids Hydroelectric Project.

2.0 METHODS

Aerial surveys of fall Chinook salmon redds were conducted in areas of the Hanford Reach consistent with past survey efforts and the historical data set (Figure 1). Eight additional sub-sections (100-B/C, 100-K, 100-N, 100-D, 100-H, 100-F, Dunes, and 300 Area) were added beginning in 2011 to monitor the abundance and distribution of fall Chinook salmon redds in areas of the Columbia River adjacent to contaminated groundwater plumes of the Hanford Site (Figure 2; DOE/RL-2018-32). These eight new sub-sections were divided so that redd counts and direct comparisons to historical records can still be made in the original areas.

The primary physical factors influencing the accuracy of aerial counts include depth of water over redds and water clarity. Wind action, available light, orientation of the river, and direction of the current can also affect redd counts. The accuracy of aerial counts also decreases with increasing numbers and density of redds within a large aggregate of redds (Visser et al. 2002). Flights are cancelled if weather conditions are not favorable (i.e., wind, fog, or low clouds). Field measurements suggest that the upper depth limit for detecting redds during aerial surveys conducted on the Hanford Reach was 3 to 4 m (10 to 13 ft) (PNL-7289), while other studies indicate that fall Chinook salmon spawn in water up to 9 m (30 ft) deep (Swan 1989); therefore, a proportion of redds located in deeper water may not be detected during aerial

surveys (PNL-7289). Because it is seldom possible to view all redds from the air, these counts provide only an annual index of relative abundance and distribution of fall Chinook salmon spawning in the Hanford Reach of the Columbia River.

Beginning in mid-October, under the terms of the HRFCPP, river flows are reduced in the morning every Sunday (the day of the week with the lowest power demand) to the Priest Rapids Dam minimum operating discharge of 1,000 m^3/sec (36,000 ft^3/sec).

This allows the Agency (NOAAF, WDFW, and CCT) and Utility (Grant, Chelan, Douglas, and BPA) Party Monitoring Team to perform a ground survey of redd distribution at Vernita Bar just downstream of Priest Rapids Dam. These drawdowns occur every Sunday morning until the initiation of fall Chinook salmon spawning has been set both above and below the 1,416 m^3/sec (50,000 ft^3/sec) flow elevations. A final drawdown is conducted on the Sunday prior to Thanksgiving to establish the minimum critical flow needed to protect pre-emergent fall Chinook salmon. This weekly reduction in river flow can afford excellent viewing conditions and, when possible, flights are scheduled concurrent with the Sunday morning drawdowns.

Flights are scheduled to encompass the entire fall Chinook salmon spawning period, usually mid-October (initiation of spawning) through the end of November (end of spawning). Three to four flights are typically conducted during this period. Early flights (October) are conducted to establish the initiation of spawning, and later flights (November) occur during and just after the peak spawning period to establish the maximum redd count for the season by area and for the entire Hanford Reach. Multiple flights are necessary to minimize the effect of poor visibility or other sources of count variability that may occur during a single flight. Multiple flights also ensure comparability within the long-term database through consistency with past efforts. As a courtesy and consistent with past practices, aerial redd count information is shared with the HRFCPP parties to assist in the implementation of protective measures.

Survey flight altitudes range from 244 to 366 m (800 to 1,200 ft) with air speeds of 120 to 161 km/hr (75 to 100 mi/hr). Widely spaced fall Chinook salmon redds are individually counted, while tightly grouped clusters of redds are estimated in groups of 10 or 50. Heavy spawning areas require multiple aerial passes to collect complete counts. Observations begin in Richland at the Interstate 182 bridge and end at Priest Rapids Dam. Flights are conducted near noon to bracket the highest angle of the sun for optimum viewing conditions. Observers wear polarized glasses, as necessary, to reduce glare. All redds observed are documented by survey area on large format printed maps.

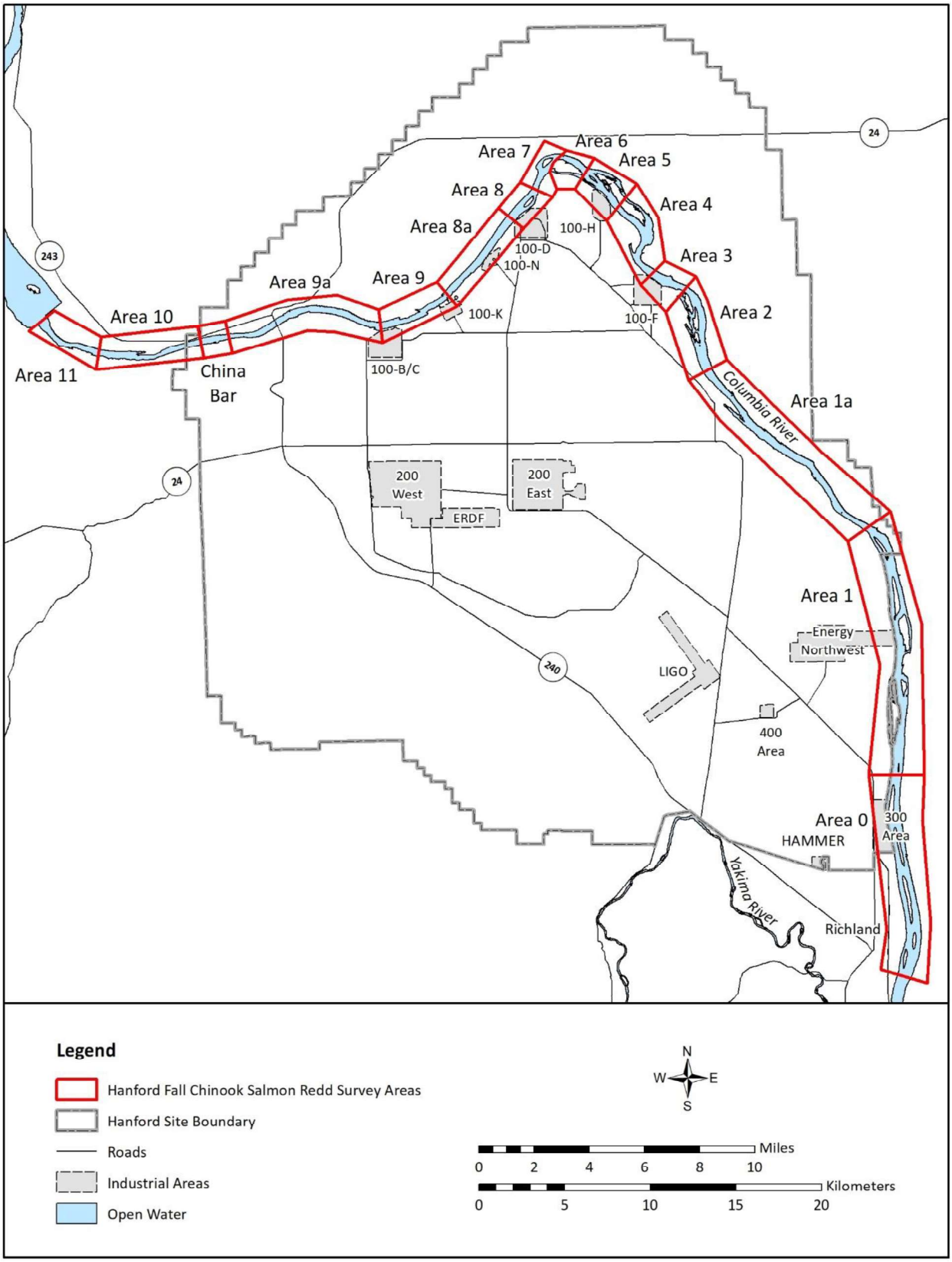


Figure 1. Aerial Survey Areas for Fall Chinook Salmon Redds Used Historically and in Calendar Year 2019

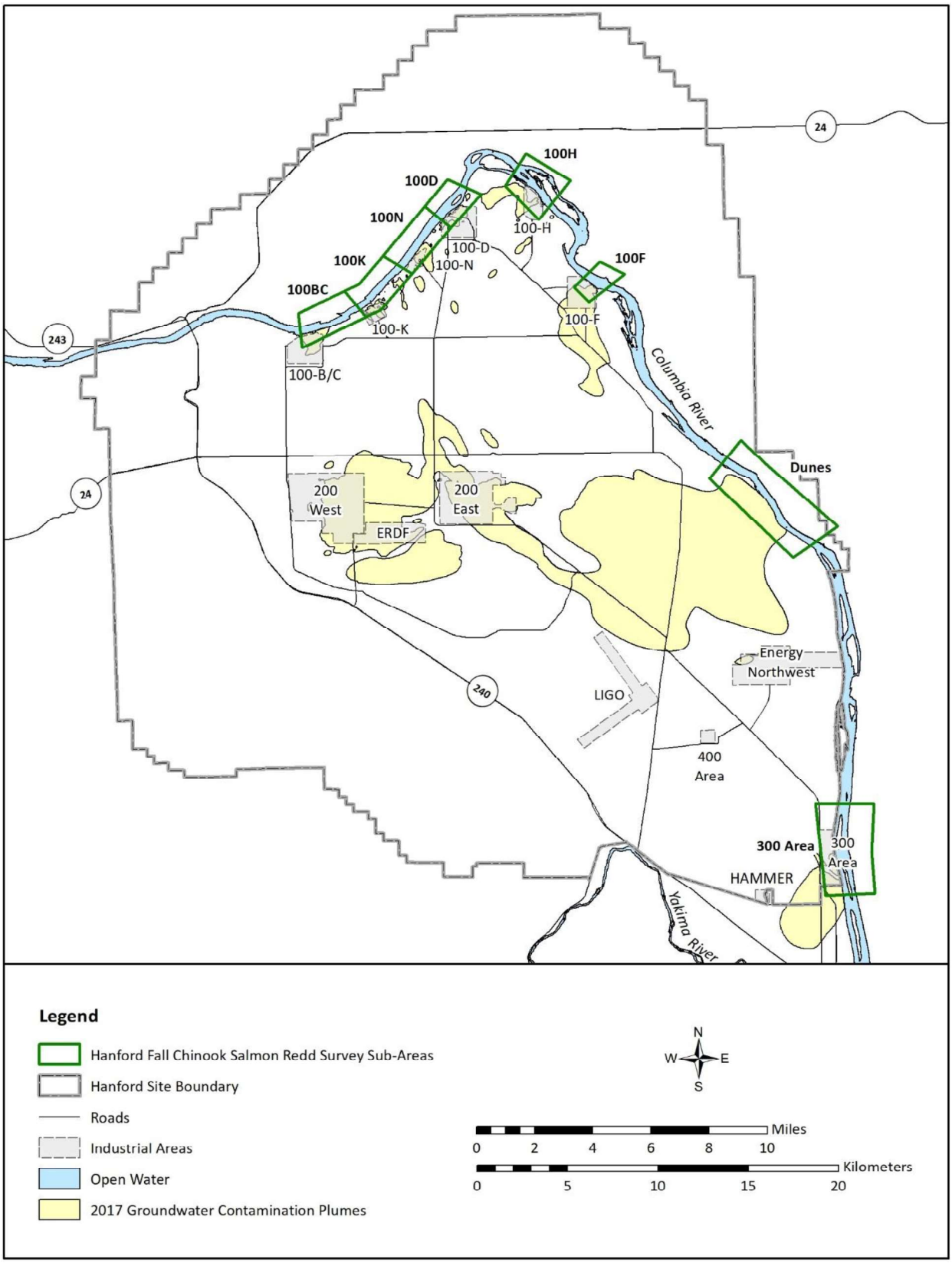


Figure 2. Fall Chinook Salmon Survey Sub-areas Adjacent to Groundwater Contamination Plumes

Because long-term trends in both redd abundance and distribution are important monitoring components, Mission Support Alliance (MSA) has taken several steps to ensure compatibility and consistency with past efforts, which include the following:

- Thoroughly reviewing and adopting past monitoring protocols
- Coordinating/training with former redd count personnel
- Coordinating and exchange of information with the WDFW and with the Grant County Public Utility District to support the ongoing HRFCPP
- Using maps detailing the entire survey reach as well as all historical sub-areas and spawning sites both as in-flight guidance documents and as field data recording forms
- Using the same air service, airplane, and pilots in 2019 that were used in previous years.

3.0 RESULTS

Three fall Chinook salmon visual aerial redd count surveys were completed along the length of the Hanford Reach during 2019. The first visual aerial redd count survey was performed on October 21, the second on November 4, and the third on November 24. The counts performed during each flight, by survey area, are shown in Table 1. The maximum count describes the highest number of redds documented in a survey area within any single flight. The visual redd count total is calculated by summing the maximum redd count from each survey area, which equaled 7,899 in 2019. The number of redds counted within the newer defined sub-areas coinciding with Hanford Site operational areas is shown in Table 2. Viewing conditions were excellent on the first two flights (October 21 and November 4). Viewing conditions on the final flight (November 24) were fair to good on the upstream portion of the reach and poor on the downstream portion of the reach. A silt plume originating along the eastern shoreline near Locke Island and the 100-F Islands obscured all redds observed on the November 4th flight below the Hanford Townsite.

Table 1. Summary of Fall Chinook Salmon Visual Aerial Redd Counts for the Calendar Year 2019 Aerial Surveys in the Hanford Reach, Columbia River.

Area	Description	10/21/2019	11/04/2019	11/24/2019	Maximum Count
0	Islands 17–21 (Richland)	0	0	0*	0*
1	Islands 11–16	11	166	0*	166*
1a	Savage Island/Hanford Slough	0	0	0	0
2	Islands 8–10	31	665	723	723
3	Near Island 7	7	308	408	408
4	Island 6 (lower half)	25	671	810	810
5	Island 4, 5, and upper 6	35	829	939	939
6	Near Island 3	2	175	300	300
7	Near Island 2	25	440	720	720
8	Near Island 1	0	140	150	150
8a	Upstream of Island 1 to Coyote Rapids	0	0	0	0

Table 1. Summary of Fall Chinook Salmon Visual Aerial Redd Counts for the Calendar Year 2019 Aerial Surveys in the Hanford Reach, Columbia River.

Area	Description	10/21/2019	11/04/2019	11/24/2019	Maximum Count
9	Near Coyote Rapids	24	112	112	112
9a	Upstream of Coyote Rapids to China Bar	0	0	0	0
China Bar	China Bar/Midway	1	20	30	30
10	Near Vernita Bar	49	2,800	3,530	3,530
11	Upstream of Vernita Bar to Priest Rapids Dam	0	6	11	11
Total		**210**	**6,332**	**7,733**	**7,899**

*Area obscured by silt plume

Table 2. Summary of Fall Chinook Salmon Visual Aerial Redd Counts for the Calendar Year 2019 Aerial Surveys by Operational Area Sub-Sections.

Sub-area	10/21/2019	11/04/2019	11/24/2019	Maximum Count
300 Area	0	0	0	0
Dunes	0	0	0	0
100-F	7	308	408	408
100-H	35	829	939	939
100-D	0	140	150	150
100-N	0	0	0	0
100-K	0	0	0	0
100-BC	24	112	112	112
Total	**66**	**1,389**	**1,609**	**1,609**

4.0 DISCUSSION

The peak annual visual redd count for 2019 (7,899) was the ninth lowest count (range: 4,018 – 20,678) in the past 20 years (2000 – 2019) and was well below the previous 10-year average (11,247). Fall Chinook salmon redd counts on the Hanford Reach in 2019 increased by 45.5% from the 2018 redd count (5,429). The historical trend in redd counts since 1948 is shown in Figure 3.

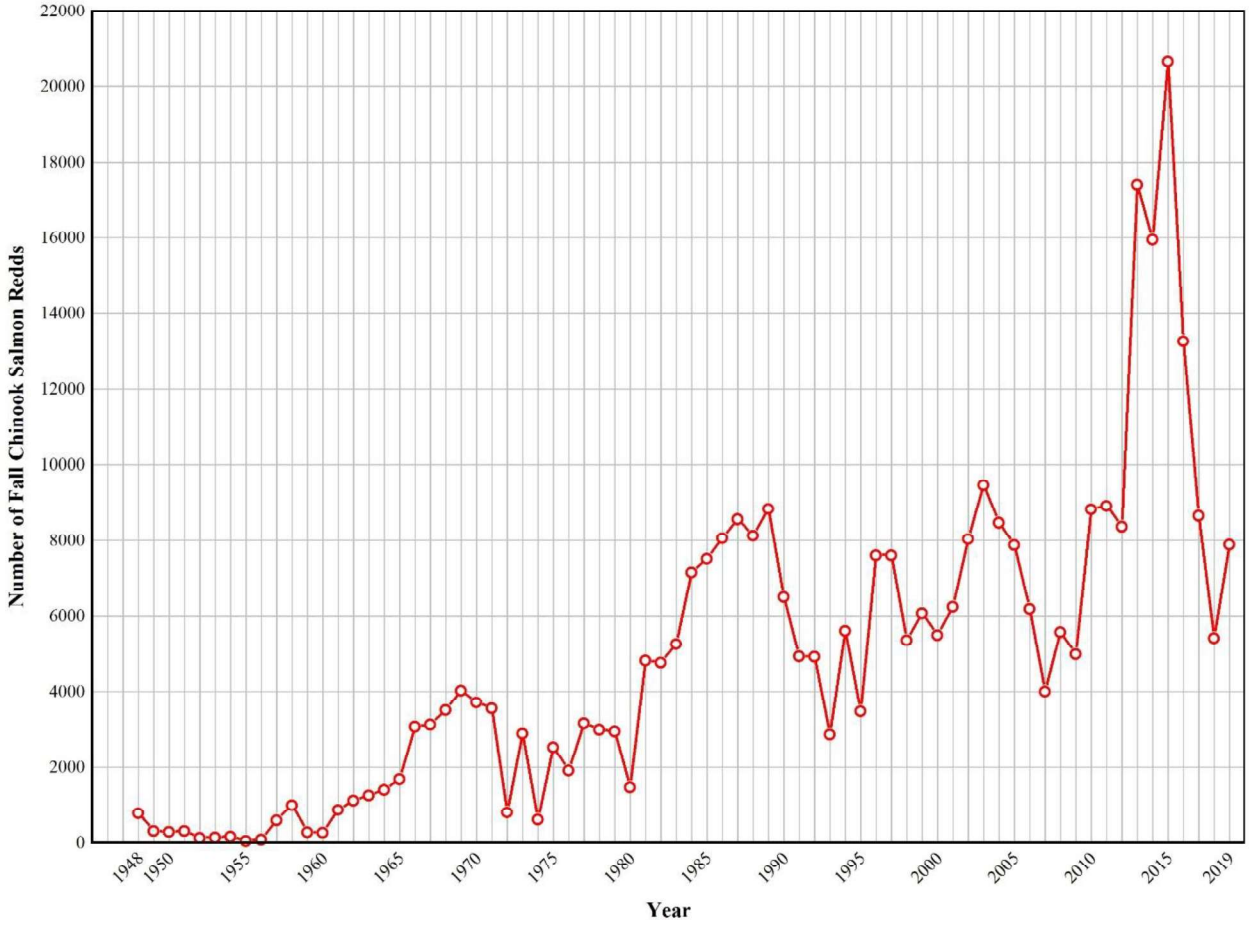


Figure 3. Visual Hanford Reach Fall Chinook Salmon Redd Counts 1948 to 2019

On November 24, 2019, a sediment plume (Figure 4) was observed beginning along the eastern shoreline near Locke Island and the 100-F Islands. The plume widened downstream and concealed all redds recorded below the Hanford Townsite on the previous survey. The source of the sediment is the recent series of landslides along the White Bluffs, the toes of which are being eroded by the Columbia River. The modern (activated in the early 1970s) landslides are the result of irrigation water distributed to unlined wastewater ponds and canals behind the bluffs starting in the 1960s (PNNL-15941; Hays and Schuster 1987; Schuster et al. 1987; PNNL-11970; Triangle Associates 2003). The irrigation water percolates down through permeable sediments perching on fine-grained sediments then moves laterally. Landslides occur where the perched water seeps out along the bluffs. The wastewater ponds behind the bluffs were completely drained in the mid-1990s in an effort to stop the slumping of the bluffs and the rate of movement in this area has gradually slowed to little or no movement in recent years (PNNL-15941).

Although the movement of the landslides has been stemmed, erosion at the toes of the landslides continues. Sediment plumes seen on survey flights are likely the result of large rapid fluctuations in river flows that cause instability and slumping of sediments along the toes of the landslides. Under normal Priest Rapids Dam operations, river elevation changes may occur in excess of 2.1 m/hr (7 ft/hr) and 4.0 m (13 ft) within a 24-hr period (Nugent et al. 2002) The night prior to November 24, 2019, discharge from Priest Rapids Dam fell from 5,494 m^3/sec (194,000 ft^3/sec) to 1,354 m^3/sec (47,800 ft^3/sec). This change in discharge generated a 3.8 m (12.4 ft) drop in river stage. Large daily flow fluctuations are typical on the Hanford Reach during the fall Chinook salmon spawning period. Figure 5 shows river gage height

changes at the United States Geological Survey (USGS) 12472800 station on the Columbia River below Priest Rapids Dam during the fall Chinook salmon spawning period in 2019.

Approximately ¼ of fall Chinook salmon spawning on the Hanford Reach occurs downstream of the Locke Island and 100-F Islands landslides and could be affected by sediment plumes developing from them. A considerable amount of geomorphically suitable fall Chinook salmon spawning habitat occurs downstream of rkm 580 (downstream of the Hanford Townsite). Fine-grained sediments, due in part to recent landslides, may be significantly impacting the habitat quality in this section of the Hanford Reach (Geist et al. 2006). Sediment plumes have been documented on aerial redd counts on the Hanford Reach by MSA since 2013. Large daily flow fluctuations from Priest Rapids Dam are likely degrading spawning habitat in this area.

MSA will continue to monitor and document sediment plumes during aerial surveys of fall Chinook salmon redds on the Hanford Reach. More information is needed on the direct effects the plumes may be having on fall Chinook salmon spawning and on the long-term quantity and quality of spawning habitat in the middle and lower sections of the Hanford Reach.

Figure 4. View of Sediment Plume Downstream of the Hanford Townsite on November 24, 2019

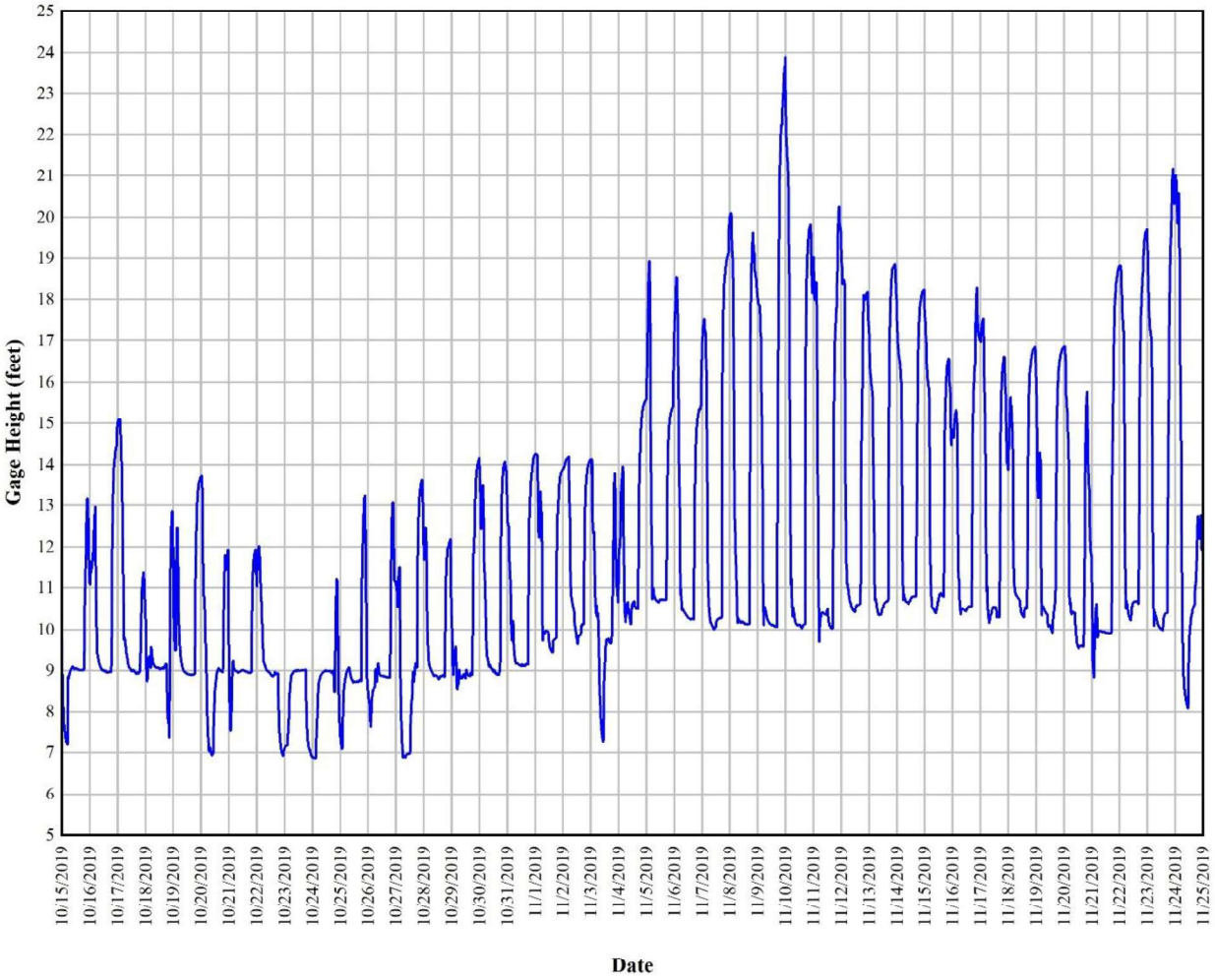


Figure 5. Gage Height changes at USGS 12472800 Columbia River Below Priest Rapids Dam, Washington during the Fall Chinook Salmon Spawning Period in Calendar Year 2019

5.0 REFERENCES

Anglin, D. R., S. L. Haeseker, J. J. Skalicky, H. Schaller, K. F. Tiffan, J. R. Hatten, P. Hoffarth, J. Nugent, D. Benner, and M. Yoshinaka. 2006. *Effects of Hydropower Operations on Spawning Habitat, Rearing Habitat, and Stranding/Entrapment Mortality of Fall Chinook Salmon in the Hanford Reach of the Columbia River*. Final Report. Columbia River Fisheries Program Office, U.S. Fish and Wildlife Service, Vancouver, Washington. Online at: https://www.fws.gov/columbiariver/publications/FINAL_HANFORD_REPORT_8-10-2006.pdf.

Dauble, D. D. and D. G. Watson. 1997. "Status of Fall Chinook Salmon Populations in the Mid-Columbia River, 1948–1992." *North American Journal of Fisheries Management* 17 (2): 283–300. Online at: http://dx.doi.org/10.1577/1548-8675(1997)017<0283:sofcsp>2.3.co;2.

DOE/EIS-0222. 1999. *Final Hanford Comprehensive Land-Use Plan Environmental Impact Statement*. U.S. Department of Energy, Washington, D. C. Online at: http://energy.gov/nepa/downloads/eis-0222-final-environmental-impact-statement-0.

DOE/RL-2009-10. 2013. *Hanford Site Cleanup Completion Framework*. Rev. 1. U.S. Department of Energy, Richland Operations Office, Richland, Washington. Online at: https://www.hanford.gov/files.cfm/Comp_Framework_Jan_%201-23-13-lfm.pdf.

DOE/RL-96-32. 2017. *Hanford Site Biological Resources Management Plan*. Rev. 2. U.S. Department of Energy, Richland Operations Office, Richland, Washington. Online at: http://www.hanford.gov/files.cfm/DOE-RL-96-32-01.pdf.

DOE-RL-2018-32. 2018. *Hanford Annual Site Environmental Report for Calendar Year 2017*. Rev. 0. U.S. Department of Energy, Richland Operations Office, Richland, Washington. Online at: https://msa.hanford.gov/files.cfm/DOE-RL-2018-32_Rev0_UPDATED.pdf.

Fulton, L. A. 1968. *Spawning Areas and Abundance of Chinook Salmon (*Oncorhynchus tshawytscha*) in the Columbia River Basin--Past and Present*. U.S. Fish and Wildlife Service Special Scientific Report--Fisheries No. 571. U.S. Fish and Wildlife Services, Bureau of commercial Fisheries, Washington, D.C. Online at: http://www.nwfsc.noaa.gov/assets/26/6638_08042010_145107_Fulton.1968-rev.pdf.

Geist, D. R., E. V. Arntzen, Y. Chien, T. P. Hanrahan, C. J. Murray, W. A. Perkins, M. C. Richmond, and Y. Xie. 2006. *Spawning Habitat Studies of Hanford Reach Fall Chinook Salmon (Oncorhynchus tshawytscha)*. Prepared for U.S. Department of Energy, Bonneville Power Administration, Division of Fish and Wildlife, Portland, Oregon. Project No. 1994-069-00, Contract No. 00000652. Online at: https://www.academia.edu/15211393/Spawning_Habitat_Studies_of_Hanford_Reach_Fall_Chinook_Salmon_Oncorhynchus_tshawytscha_Final_Report.

Hays W. H. and R. L. Schuster. 1987. *Maps Showing Ground Failure Hazards in the Columbia River Valley Between Richland and Priest Rapids Dam, South-Central Washington*. Miscellaneous Investigation Series, Map I-1699, U.S. Geological Survey, Reston, Virginia.

Healey, M. C. 1991. *The Life History of Chinook Salmon (Oncorhynchus tshawytscha)*. University of British Columbia Press, Vancouver, British Columbia, Canada.

HNF-52190. 2012. *Fall Chinook Redd Monitoring Report Calendar Year 2011*. Rev. 0. Mission Support Alliance, Richland, Washington. Online at: http://www.hanford.gov/files.cfm/hnf-52190_-_rev_00%20public%20relesed.pdf.

HNF-53665. 2012. *Steelhead Redd Monitoring Report for Calendar Year 2012*. Rev. 0. Mission Support Alliance, Richland, Washington. Online at: http://www.hanford.gov/files.cfm/hnf-53665_-_rev_00.pdf.

HNF-54808. 2013. *Hanford Reach Fall Chinook Redd Monitoring Report for Calendar Year 2012*. Rev. 0. Mission Support Alliance, Richland, Washington. Online at: http://www.hanford.gov/files.cfm/hnf-54808_-_rev_00_nc.pdf.

HNF-56705. 2014. *Hanford Site Steelhead Redd Monitoring Report for Calendar Year 2013*. Rev. 0. Mission Support Alliance, Richland, Washington. Online at: http://www.hanford.gov/files.cfm/HNF-56705_-_Rev_00.pdf.

HNF-56707. 2014. *Hanford Reach Fall Chinook Redd Monitoring Report for Calendar Year 2013*. Rev. 0. Mission Support Alliance, Richland, Washington. Online at: http://www.hanford.gov/files.cfm/HNF-56707_-_Rev_00.pdf.

HNF-58823. 2015. *Hanford Reach Fall Chinook Redd Monitoring Report for Calendar Year 2014*. Rev. 0. Mission Support Alliance, Richland, Washington. Online at: http://www.hanford.gov/files.cfm/HNF-58823_-_Rev_00.pdf.

HNF-59813. 2016. Hanford Reach Fall Chinook Redd Monitoring Report for Calendar Year 2015. Rev. 0. Mission Support Alliance, Richland, Washington. Online at: https://www.hanford.gov/files.cfm/HNF-59813_-_Rev_00.pdf.

HNF-63012. 2018. Hanford Site Ecological Monitoring Report for Calendar Year 2017. Rev. 0. Mission Support Alliance, Richland, Washington. Online at: https://www.hanford.gov/files.cfm/HNF-63012_-_Rev_00_cleared.pdf.

HNF-64540. 2020. Hanford Reach Fall Chinook Salmon Redd Monitoring Report for Calendar Year 2017. Rev. 0. Mission Support Alliance, Richland, Washington. Online at: https://www.hanford.gov/page.cfm/EcologicalMonitoring.

HNF-64542. 2020. Hanford Reach Fall Chinook Salmon Redd Monitoring Report for Calendar Year 2018. Rev. 0. Mission Support Alliance, Richland, Washington. Online at: https://www.hanford.gov/files.cfm/HNF-64542_-_Rev_00.pdf.

Magnuson-Stevens Fisheries Conservation and Management Act, 16 U.S.C. 1801-1884.

Myers, J. M., R. G. Kope, G. J. Bryant, D. Teel, L. J. Lierheimer, T. C. Wainwright, W. S. Grant, F.W. Waknitz, K. Neely, S. T. Lindley, and R. S. Waples. 1998. *Status Review of Chinook Salmon from Washington, Idaho, Oregon, and California*. U.S. Department of Commerce: NOAA Technical Memorandum NMFS-NWFSC-35. 443 pp. Online at: http://www.westcoast.fisheries.noaa.gov/publications/status_reviews/salmon_steelhead/chinook/sr1998-chinook1.pdf.

National Environmental Policy Act of 1969, 42 U.S.C. 4321, et seq.

Netboy, A. 1958. *Salmon of the Pacific Northwest: Fish vs. Dams*. Binfords & Mort, Portland, Oregon.

Nugent, J., T. Newsome, P. Hoffarth, M. Nugent, W. Brock, and M. Kuklinski. 2002. 2001 Evaluation of Juvenile Fall Chinook Salmon Stranding on the Hanford Reach of the Columbia River. Prepared for the Bonneville Power Administration, Portland, Oregon and the Grant County Public Utility District No. 2, Ephrata, Washington. BPA Contract Number 9701400 and GCPUD Contracts Document 97BI30417.

PNL-7289. 1990. *Spawning and Abundance of Fall Chinook Salmon (*Oncorhynchus tshawytscha*) in the Hanford Reach of the Columbia River, 1948–1988*. Pacific Northwest Laboratory, Richland, Washington. Online at: http://pdw.hanford.gov/arpir/index.cfm/docDetail?accession=D196110653.

PNNL-11970. 1998. *Monitoring bank erosion at the Locke Island Archaeological National Register District: Summary of 1996/1997 field activities*. Pacific Northwest Laboratory, Richland, Washington.

PNNL-15941. 2006. *Past, Present, Future Erosion at Locke Island*. Pacific Northwest Laboratory, Richland, Washington. Online at: https://www.pnnl.gov/main/publications/external/technical_reports/PNNL-15941.pdf.

Schuster R. L., A. F. Chleborad, and W. H. Hays. 1987. *Irrigation-induced landslides in fluvial-lacustrine sediments, south-central Washington State*. In 5th International Conference and Field Workshop on Landslides, Christchurch, New Zealand, pp. 147-156.

Swan, G. A. 1989. "Chinook Salmon Spawning Surveys in Deep Waters of a Large, Regulated River." *Regulated Rivers: Research & Management* 4 (4): 355–370. Online at: http://www.nwfsc.noaa.gov/assets/2/7293_07122012_094837_Swan.1989.pdf.

Triangle Associates. 2003. *White Bluffs Landslides: Assessment Report*. Prepared under contract to the U.S. Institute for Environmental Conflict Resolution and the U.S. Fish and Wildlife Service for the Hanford Reach National Monument, Seattle, Washington.

USACE. 2006. Hanford Reach Fall Chinook Protection Program, Hanford Reach Fall Chinook Protection Program Executed Agreement. U.S. Army Corps of Engineers. Online at: http://pweb.crohms.org/tmt/documents/wmp/2006/draft/app7.pdf.

United States Geological Survey Gauging Station # 12472800 Columbia River Below Priest Rapids Dam, Washington. Online at: https://waterdata.usgs.gov/usa/nwis/uv?site_no=12472800.

Visser, R., D. D. Dauble, and D. R. Geist. 2002. "Use of Aerial Photography to Monitor Fall Chinook Salmon Spawning in the Columbia River." *Transactions of the American Fisheries Society* 131 (6): 1173–1179. Online at: http://dx.doi.org/10.1577/1548-8659(2002)131<1173:uoaptm>2.0.co;2.